Accelerated Bridge Strengthening using UHP(FR)C

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UHPFRC = Ultra-High Performance Fiber Reinforced Cementitious Composites
Performance of UHPFRC (Ultra-High Performance Fiber Reinforced Cementitious Composites)

**Compressive strength:**
130 – 180 MPa \((19 – 26 \text{ ksi})\)

**Modulus of elasticity:**
45 – 50 GPa \((7'000 \text{ ksi})\)

- **Impermeable** ➞ compact matrix: powders and particles (<0.04”)
- **Fiber** reinforced with steel fibers \(l = \frac{1}{2}”\), \(l/d > 65; > 3 \text{ vol.\%}\)
  (synthetic fibers are too soft !)
- **Hardening** (in tension)
- **Shrinkage and Creep**
Basic concept of enhancement of bridges using UHP(FR)C

**UHPFRC = Ultra-High Performance Fiber Reinforced Cement-based Composites**

**UHPFRC is not a concrete!**

- use UHPFRC to enhance R-concrete

### Reinforced Concrete

**Shortcomings:**

- limited durability under severe exposure: rebar corrosion, AAR, frost
- high maintenance cost
- heavy weight, material consuming
- slow construction

Interface surface preparation by hydro jetting or sandblasting; wetting before UHPFRC casting ➔ bond strength >> concrete tensile strength
Conceptual idea

- exposed reinforced concrete is not durable!
- often structural capacity (fatigue and ultimate resistance) of slabs and other structural elements is not sufficient!
Conceptual idea: *enhance RC using UHPFRC!*

- protective watertight UHPFRC layer to improve durability
- increase structural capacity (stiffness, ultimate resistance, fatigue resistance)
Strengthening = adding a layer of R-UHPFRC as additional reinforcement to the RC section

Fulfill several functions with 1 layer:
1) increase resistance in bending and shear
2) increase stiffness to reduce fatigue stresses
3) act as a waterproofing layer
Conceptual idea (1999): enhance RC using UHPFRC!

**UHPFRC** for waterproofing

$t_u = 1''$

**R-UHPFRC** for strengthening

($t_u = 1^{3/4}''$ to $3'') +$ steel rebars

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**composite behavior of (R-)UHPFRC – RC elements**

**17 years of research and 12 PhD theses at the EPFL (Swiss Federal Institute of Technology)**
Structural response and sectional analysis of R-UHPFRC – RC composite members

Ultimate bending resistance:

Fatigue stresses and fatigue resistance:
Ultra-High Performance Fibre Reinforced Cement-based composites (UHPFRC)

Construction material, dimensioning and application
Ultra-High Performance Fibre Reinforced Cement-based composites (UHPFRC)

Construction material, dimensioning and application
**UHPFRC** technology is cost-effective!

*more than 50 applications in Switzerland since 2004: why?*

1: UHPFRC fabrication cost (1’900 US dollars / yd$^3$)

2: **Construction cost**: several requirements are fulfilled with one UHPFRC casting/layer ➔ *determinant!*

3: **Intervention cost** = construction cost + indirect (user) costs ➔ *added value for the owner*

4: **Life cycle cost**: reduction of maintenance and environmental impact ➔ *added value for owner and society*
Rebar corrosion and higher traffic loads: 
➔ repair – strengthening - replacement
Conventional repair and retrofit is not sufficient! Reinforced concrete needs to be enhanced!

Fulfill several functions: restoration of elements; waterproofing; protection against water and chloride ions; increase in structural capacity (bending, shear, fatigue); drivable surface; simplify construction process and reduce intervention time.

➔ cost effective
Enhancement of the Chillon Viaducts 2014/15

Functions of R-UHPFRC:

- strengthening of deck slab in the transverse direction: bending, shear and fatigue resistance
- increase in stiffness and strength in the longitudinal direction
- waterproofing of slab
- no increase in dead load
- short duration of intervention

R-UHPFRC:

- thickness: 2” (50mm)

Detailed design by:
Monod-Piguet + Associés IC / GVH
Enhancement of the Chillon Viaducts 2014/15

July/August 2014 and June 2015: Casting of 1’600 yd³ UHPFRC on each 1.30 miles long viaduct

Intervention cost:

22 US dollars / ft² deck surface

Contractor: WALO Bertschinger SA
UHPFRC ready mix plant on site
maximum slope: 7%

working
joint detail

curing
Enhancement of the Cudrex Viaduct (2016)

**Concept:** accelerated intervention in 8 work phases of 36 hours

Saturday 5pm – Monday 5am

Total length: 500yd (450m)

Owner: Canton of Vaud

**ABE : Accelerated Bridge Enhancement**

Temperature dependent strength evolution of UHPFRC Holcim 710

Compressive strength (MPa)

- 20°C
- 10°C
- 5°C

10ksi

Project: Ing. D. Willi, Montreux
Enhancement of the Cudrex Viaduct (2016)

**Concept:** accelerated intervention: bridge in service during the week

Costs: UHPFRC works **28 US dollars per ft\(^2\) bridge deck surface** + further works (piers, bearings, dilation joints) = about **20%** of hypothetical replacement project.
Enhancement of 3 highway viaducts (2017/18)

Cross section at support:

1: increasing ultimate bending resistance:
   $h_u = 4''$, $\phi_{su} = 0.8'' @ 4''$, 2 layers

2: new curbs
   asphalte pavement: 3''

3: rehabilitation of corrosion damaged zones using UHPFRC
   total length: 1’100yd

Owner: Swiss Federal Roads Office
Principle of structural strengthening using R-UHPFRC

- increase hogging moment capacity by adding R-UHPFRC tension chord
- transverse rebars for load distribution and increase in transverse stiffness

check at **ULS**:  
- plastic sagging moment + plastic hogging moment > overall acting moment  
- ultimate shear resistance > acting shear force  
- concrete compressive stress < concrete strength

check at **SLS**: maximum UHPFRC tensile strain < 1 %

check at **FLS**: fatigue stress in rebars < fatigue endurance limit
Rehabilitation of corrosion damaged zones using UHPFRC : 2017

Photos: 13 September 2017
Traditional: Repair of steel rebar corrosion damage using **repair mortar**

Principle:

Invasive concrete removal up to 4” depth => criterion **remaining chloride content**

=> important reduction of cross section: => temporary support

=> possibly additional rebars / surface protection

⇒ *conventional method = not efficient!*
Rehabilitation of local steel rebar corrosion damage using **UHPFRC**

**Principle:**

- Minimal concrete removal behind rebar
- Re-profiling using **UHPFRC**
- Waterproof layer around the damaged rebar
- No chloride migration to the rebar
- **UHPFRC** tensile resistance to compensate section loss due to corrosion
UHPFRC mixing plant

Photo: 13 September 2017
General concept of UHPFRC intervention

Objectives: 1 UHPFRC layer for:
- waterproofing protection
- repair of local damage
- drivable surface
- structural strengthening
- simplified execution
- reduce time for construction works
General concept of UHPFRC intervention to enhance bridge performance

(deck surface = 5’500 ft²)

* $h_U = \text{thickness of UHPFRC layer}$
UHPFRC intervention: General cross-section at mid-span (Phase II)

**Detail 2: Deck slab reinforcement**

1) HPW jetting removal of 1 to 1.5 inches of concrete (depending on condition)
2) Deck surface: New **UHPFRC** layer (thickness min. 1.5 inches) including transversal rebars

Above joints between pre-cast box girders: Removal of unsound concrete + filling with **UHPFRC** (existing rebars kept in place)

**Main benefits:**

**Structural strengthening:**
1) Transversal stiffness + resistance (↗)
   → Reducing relative vert. displacement of box-girders (= eliminating source of longitudinal cracking in deck slab)

**Enhanced durability:**
1) Waterproofing (entire cross section)
2) Local repair of concrete damage
   → Protection of underlying pre-cast box girders subjected to water infiltrations from top (cracked deck slab) + chloride induced corrosion of steel rebars and prestressing
**UHPFRC intervention: Phase III (parapet & barrier)**

**Detail 3: Restoring parapet**

- HPW jetting removal of min. 1 inch of concrete
- NEW UHPFRC waterproofing layer (thickness min. 1 inch)

**Detail 3: Restoring concrete barrier**

- \( h_U = \text{min} 1.0" \)
- HPW jetting removal of min. 1 inch of concrete
- NEW UHPFRC waterproofing layer (thickness min. 1 inch)
Removal of armored joints on abutments and creating a **UHPFRC «sealing»**

**Integral bridge**
(removal of armored joints + continuous **UHPFRC** layer → removal of last «weak detail» to enhance durability and reduce maintenance)

**Detail 6: UHPFRC «sealing»**

Continuous **UHPFRC** layer over existing approach slab

**UHPFRC «sealing»**
Thank you!

- UHPFRC Technology to enhance bridge performance
- ABE = Accelerated Bridge Enhancement
- validated by many applications
- cost effectiveness proven

➔ from 🇨🇭 to 🇺🇸